10019976-1

UNITED STATES PATENT APPLICATION

for

METHOD AND APPARATUS FOR DISCOVERY OF OPERATIONAL BOUNDARIES FOR SHMOO TESTS

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METHOD AND APPARATUS FOR DISCOVERY OF OPERATIONAL BOUNDARIES FOR SHMOO TESTS

a Field of Invention

~~TECHNICAL FIELD~~

The present invention relates generally to the field of hardware testing and pertains more particularly to a method of and apparatus for discovering the operational range of an electronic device.

a Background of the Invention

~~BACKGROUND ART~~

Testing of electrical components, such as microprocessors, and other hardware components ensures proper operation of the particular components. In addition, testing of the hardware components helps define the operational specifications, as defined by a plurality of operating parameters, over which the hardware component is operational.

Various operating parameters are varied to test for and discover the electrical operating ranges of the hardware component. A specific set of conditions as defined by the various operating parameters is referred to as a point.

Previously, automatic testing of the hardware device to discover the electrical operating ranges of a hardware component entailed testing of all the points within a predefined testing region. This process is undesirable for various reasons, all of which increase the amount of time needed for testing.

Prior art Figure 1 is a plot diagram 100 illustrating tested points within a predefined testing region. In the diagram 100, two operating parameters are varied. Points designated by the letter "F" indicate a failure by the hardware component. Points designated by a "dot" indicate an successful operation by the hardware component. The testing region is defined by a first operating parameter on the horizontal axis, and a second operating parameter on the vertical axis, and includes all the points in diagram 100. The first operating parameter

varies with values ranging from 3.3 to 3.465. The second operating parameter varies with values ranging from 1.71 to 1.80. These parameters can include input/output voltages, clock frequencies, and temperature, etc.

In the past, testing of all the points in a predefined testing region often times would not provide any additional useful information. For example, once an operational boundary is found, further points within the operational boundary need not be tested, and further points outside the operational boundary need not be tested. Although further testing of points inside or outside of the operational boundary was unnecessary, these points were still tested.

For example, looking at diagram 100, the point with parameter coordinates of 1.8 and 3.3 is clearly within the operational range of the hardware component and need not be tested. Similarly, the point with parameter coordinates of 1.71 and 3.465 is clearly outside of the operational range of the hardware component and also need not be tested. No further information is gained from testing these two points.

Testing of points within a testing region adds and wastes a significant amount of time for each point tested unnecessarily. Referring back to Prior Art Figure 1, once the operational boundary is fully determined within the testing region, no other points need be tested. For example, once adjacent failure points that are also adjacent to operational points are discovered within the region, testing of the remaining points provides limited or no further information. Points within region 110 define the operational boundary for the hardware component tested in diagram 100. For example, failure points outside of region 110 are unnecessarily tested.

Furthermore, the predefined testing region provides a limitation to the discovery of the operational specifications of the hardware component. The testing region is defined manually as a best guess estimate. Should the testing region be too small, the region may not

include all of the operational boundary for the hardware device. In that case, the testing region needs further manual expansion and retesting of the expanded region. On the other hand, if the testing region is too large, the region will include too many unnecessary points for testing, thereby wasting testing time, energy, and resources.

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Summary of the Invention

~~DISCLOSURE~~ OF THE INVENTION

Embodiments of the present invention describe a method and apparatus for conducting a boundary search for shmoo tests on an electronic device. Specifically, a method of testing operational boundaries is described in one embodiment of the present invention. The method discloses the discovery of an operational range for a hardware device over a plurality of varying operating parameters. The operational range is discovered by testing points, as defined by the plurality of varying operating parameters, to discover an operational boundary of the device. The operational boundary comprises a plurality of boundary points that lie just outside of the operational range of the device. The operational boundary is discovered automatically and without testing all of a plurality of interior operational points within the operational boundary.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects and advantages of the present invention will be more readily appreciated from the following detailed description when read in conjunction with the accompanying drawing, wherein:

PRIOR ART FIG. 1 is a plot diagram of a testing region showing tested points of failure and operation.

Figure 2 is a plot diagram showing tested points of failure and operation, in accordance with one embodiment of the present invention.

Figure 3 is a flow diagram illustrating steps in a method for automatically discovering the operational boundary of an electronic device.

Figure 4 is a flow diagram illustrating steps in a method for automatically discovering the operational boundary of an electronic device, and for determining whether the discovered operational boundary is part of an inner fault region

The drawings referred to in this description should be understood as not being drawn to scale except if specifically noted.

BEST MODES FOR CARRYING OUT THE INVENTION

Reference will now be made in detail to embodiments of the present invention, a method for discovering operational boundaries of an electronic device, examples of which are illustrated in the accompanying drawings. While the invention will be described in conjunction with the preferred embodiments, it will be understood that they are not intended to limit the invention to these embodiments. On the contrary, the invention is intended to cover alternatives, modifications and equivalents, which may be included within the spirit and scope of the invention as defined by the appended claims.

Furthermore, in the following detailed description of the present invention, numerous specific details are set forth in order to provide a thorough understanding of the present invention. However, it will be recognized by one of ordinary skill in the art that the present invention may be practiced without these specific details. In other instances, well known methods, procedures, components, and circuits have not been described in detail as not to unnecessarily obscure aspects of the present invention.

Some portions of the detailed descriptions which follow are presented in terms of procedures, steps, logic blocks, processing, and other symbolic representations of operations on data bits that can be performed on computer memory. These descriptions and representations are the means used by those skilled in the data processing arts to most effectively convey the substance of their work to others skilled in the art. A procedure, computer executed step, logic block, process, etc., is here, and generally, conceived to be a self-consistent sequence of steps or instructions leading to a desired result. The steps are those requiring physical manipulations of physical quantities. Usually, though not necessarily, these quantities take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated in a computer system. It has proven convenient at times, principally for reasons of common usage, to refer to these signals

as bits, values, elements, symbols, characters, terms, numbers, or the like.

It should be borne in mind, however, that all of these and similar terms are to be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities. Unless specifically stated otherwise as apparent from the following discussions, it is appreciated that throughout the present invention, discussions utilizing terms such as “testing,” or "discovering," or "varying," or "storing," or "inputting," or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission or display devices.

DISCOVERING OPERATIONAL BOUNDARIES IN A SHMOO TEST

Accordingly, the present invention provides a method and system for discovering operational boundaries that defines an operational range over which an electronic device is functional. The present invention provides for efficient use of resources (e.g., computer, human, etc.) when testing for the operational boundary of an electronic device. In addition, the present invention reduces the amount of testing subjected on an tested electronic device, thereby increasing the reliability of the test by reducing test and device irregularities.

Embodiments of the present invention refer to the testing of an electronic device. Other embodiments are well suited to the testing of any device in order to determine the operational range of the device. For example, in one embodiment, the device is a hardware device, such as, a microprocessor, or a processor embedded on an integrated circuit (IC) chip.

Some embodiments of the present invention are implemented on computer-readable and computer-executable instructions which reside, for example, in computer-readable media of a computer system. The computer system has sufficient hardware (e.g., processor, memory, display, etc.) to run tests on critical electronic components to determine their operational range.

The flow charts in Figures 3 and 4 in combination with Figure 2, disclose a method for automatically discovering the operational boundary that defines the operational range of an electronic device. In one embodiment, the testing for the operational boundary of an electronic device is the automatic implementation of a shmoo test without testing all of a plurality of interior operational points and non-operational points within a pre-defined testing region.

Referring now to Figure 2, the plot diagram 200 illustrates the discovery of an operational boundary for an electronic device, in accordance with one embodiment of the present invention. In the diagram 200, two operating parameters are varied. Points designated by the letter "F" indicate a failure by the electronic device. Points designated by a dot (".") indicate a successful operation by the electrical device.

Although the electronic device is affected by a plurality of parameters that vary, only two parameters are varied in the present embodiment, while holding all remaining parameters constant. Other embodiments are well suited to varying more than two parameters during a test for the operational boundary.

The diagram 200 is defined by a first operating parameter 210 that varies on the horizontal axis, and a second operating parameter 220 that varies on the vertical axis, in one embodiment. The first operating parameter 210 varies with values ranging from 1.00000 to 2.60000. The second operating parameter 220 varies with values ranging from 2.00000 to 4.6000. The diagram 200 illustrates an operating region for the

electronic device, as defined by the first and second operating parameters 210 and 220, respectively. The operating region is a region over which the electronic device may or may not be functional, in other words, the operating region contains further regions of operability and non-operability.

The first and second operating parameters 210 and 220 can include any electrical parameter, such as, input/output voltages, clock frequencies, etc. Furthermore, other embodiments are well suited to testing the electronic device by varying other parameters that have an effect on the operating performance of the electronic device, such as, temperature, etc.

The diagram 200 in Figure 2 illustrates an operational boundary 250 of the electronic device. The boundary 250 is defined by the continuous and adjacent pattern of plotted "Fs." Table 1 shows the coordinates, as defined by the first and second parameters 210 and 220, for each of the plurality of boundary points of the operational boundary 250.

Failure Point	First Parameter	Second Parameter
Initial Failure Point	1.95	3.85
Failure Point	1.90	3.85
Failure Points	1.85	3.70-3.80
Failure Points	1.80	3.50-3.65
Failure Points	1.75	3.35-3.45
Failure Points	1.70	3.15-3.30
Failure Points	1.65	2.95-3.10
Failure Points	1.60	2.80-2.90
Failure Point	1.55	2.75
Failure Points	1.60-1.65	2.70
Failure Points	1.70-1.75	2.75
Failure Points	1.80-1.85	2.80
Failure Point	1.90	2.85
Failure Points	1.95-2.00	2.90
Failure Points	2.05-2.10	2.95
Failure Points	2.15-2.25	3.00
Failure Point	2.30	3.05
Failure Points	2.35	3.10-3.80
Failure Points	2.30-2.00	3.85
Back to Initial Failure Point		

Table 1: Failure Points in the Operational Boundary

The operational boundary 250 defines an interior region 230. The interior region 230 is the operational range of the electronic device and defines points, as defined by the first and second parameters 210 and 220, where the electronic device is functional. In the test for discovering the operational boundary 250, as disclosed in flow charts 300 and 400, operational points that are tested indicate that the device successfully boots up and runs test applications at the point tested.

The operational boundary 250 also defines an exterior region 235. The exterior region 235 is outside of the operational range of the electronic device, and defines points, as defined by the first and second parameters 210 and 220, where the electronic device is non-functional. In the test for discovering the operational boundary 250, as disclosed in flow charts 300 and 400, non-functional points that are tested indicate that the device does not successfully boot up and run test applications at the point tested. In another embodiment, the process as disclosed in flow charts 300 and 400 is able to determine the type of fault at a non-functional or non-operational point. In another embodiment, the type of fault is indicated on a plot of tested points, such as, the plot diagram of Figure 2.

Figures 3 and 4 are flow charts 300 and 400 illustrating steps in a method for discovering an operational boundary that defines an operational range of an electronic device, in accordance with one embodiment of the present invention. The operational range is defined over a plurality of varying operating parameters. By testing points, as defined by the plurality of varying operating parameters, an operational boundary of said device is discovered, such as, the operational boundary 250 of Figure 2. The operational boundary is comprised of a plurality of boundary points just outside of the operational range. The plurality of boundary points is a plurality of failure points. Furthermore, the operational boundary is discovered without testing all of a plurality of interior operational points within the operational boundary. In another

embodiment, the method disclosed in flow charts 300 and 400 is performed automatically.

Referring now to Figure 3, to discover the operational boundary of an electronic device, the present embodiment begins at a known operational point, a starting point, in step 310. The known operational point is predefined by a user, and is known to be within the operational boundary of the electronic device. For example, referring to Figure 2, a known operational point is the point ("x") at coordinates (1.95, 3.50).

Continuing with step 310, the present embodiment tests adjacently coupled points in a first direction. In one embodiment, the direction is defined by varying one parameter in an increasing manner from the starting point. All the other parameters in the plurality of parameters that could affect the electronic device are held constant. Referring now to Figure 2, beginning from the starting point "x", the direction proceeds upwards in diagram 200 by varying the second operating parameter 220 in an increasing manner. All the other plurality of parameters, including the first parameter 210, are held constant. Other embodiments are well suited to any number of directions, e.g., varying the one parameter in decreasing fashion, or varying one or more parameters in linear and non-linear manners, etc.

Also, the present embodiment tests adjacently coupled points in the aforementioned first direction until a failure point, an initial failure point, is discovered or detected, in step 310. Referring now to Figure 2, the first failure point detected is the initial failure point at the coordinates (1.95, 3.85). The initial failure point is assumed to be one of the plurality of boundary points that comprise the operational boundary 250 of the electronic device.

In another embodiment, the present embodiment tests adjacently coupled points in the aforementioned direction until reaching an operational limit point that resides outside the operational limit of the component being tested. The operational limits of the component are

predefined by a user. For each parameter in the plurality of parameters that affects the electrical properties of the electrical device, an upper and lower limit is set. The upper and lower limit defines the upper and lower boundaries of an operating limit for the electrical device for that parameter. By combining the upper and lower limits for each of the parameters, an operational limit for the device can be determined. Points outside the operational limit are determined to be non-operational, such that, these points are defined as failure points. Points within the operation limit can be operational or non-operational (e.g., failure point).

Before reaching the initial failure point or the operational limit, the present embodiment tests points that are operational and are within the operational boundary of the device. The present embodiment then sets the initial failure point, or the operational limit point, as the last known failure point, in step 320. Further, the present embodiment sets a beginning point as the last known operational point before reaching the last known operational point, in step 330.

From the initial failure point, or the operational limit point, the present embodiment tests for and discovers each of the plurality of boundary points that are adjacently coupled in succession until returning to the initial failure point. More specifically, the present embodiment tests points adjacent to the last known failing point in a circular direction, in step 340. The present embodiment starts from the last known operational point that is adjacent to the last known failing point until discovering a new failing point, or alternatively, the beginning point.

In one embodiment, each of the plurality of boundary points that comprise the operational boundary are adjacently coupled to another boundary point and to an interior operational point. A point in the plot diagram 200 potentially can have eight adjacent points. For example from the initial failure point (1.95, 3.85), adjacent points are as follows: 2.00, 3.90; 1.95, 3.90; 1.90, 3.90; 1.90, 3.85; 1.90, 3.80; 1.95, 3.80; 2.00, 3.80; and 2.00, 3.85.

Each of the plurality of boundary points are discovered in succession. The present embodiment tests points adjacent to the last known failing point, a boundary point, in a circular direction, in step 340. In one embodiment, the circular direction is in a clockwise direction. In another embodiment, the circular direction is in a counter-clockwise direction.

Continuing with step 340, the adjacent points that are tested are selected by moving in a clockwise direction from a known operational point that has been tested, and that is adjacent to the last known failing point, in one embodiment of the present invention. The adjacent points are tested until another failing point, a new failing point, or the beginning point is discovered or detected. This new failing point is also one of the plurality of boundary points that comprise the operational boundary of the electronic device.

For example, from the initial failing point (1.95, 3.85), the known operational point (1.95, 3.80) is also adjacent to the initial failing point, and has been previously tested. Moving in a clockwise direction from that known operational point, the first adjacent point that is tested is at the coordinates (1.90, 3.80). This point is an operational point. The next point selected for testing is at the coordinates (1.90, 3.85) and is the new failing point.

In another embodiment, if a point to be tested has been previously tested in the present test cycle, then the results from the previous test are used to determine if that point is operational or non-operational.

The process is repeated for every new failing point that is discovered. In condition step 350, the present embodiment determines if the point discovered is a new failing point. If the discovered failing point is a new failing point, then the flow chart 300 proceeds to condition step 360. If the discovered failing point is not a new failing point, it is necessarily the beginning point, and the flow chart 300 proceeds to "A," as

disclosed in Figure 4, to determine if the operational boundary is part of an interior fault region.

Returning to step 360, the flow chart 300 determines if the new failing point is the initial failing point, in one embodiment of the present invention. If the new failing point is the initial failing point, then the process in flow chart 300 proceeds to step 370. If the new failing point is not the initial failing point, then the process in flow chart 300 proceeds to step 390.

If the new failing point is the initial failing point, then flow chart 300 determines if the new failing point was approached following in the first direction, in condition step 370. This is accomplished to test for an anomalous operational boundary having boundary points possibly separated from other points in the plurality of boundary points by a single operational point. This embodiment ensures proper discovery of the entire boundary region that defines the operational range of the tested electronic device. As such, if the new failing point was approached in the first direction, then flow chart 300 proceeds to "A," as disclosed in Figure 4. On the other hand, if the new failing point is the initial failing point, but was not approached in the first direction, then the flow chart 300 proceeds to step 390.

Returning to step 390, the present embodiment sets the last known failing point to the new failing point. Thereafter, flow chart 300 proceeds back to step 340 to discover another new failing point. This process is recursively applied, new failure point after new failure point, until discovery of each of the plurality of boundary points that defines the operational boundary of the tested electronic device.

Figure 4 is a flow chart 400 illustrating steps in a method for determining whether a plurality of boundary points is part of an interior fault region, in accordance with one embodiment of the present invention. The flow charts in Figures 3 and 4 combine to form a method for determining an operational boundary of an electronic device. The flow

chart 400 is implemented to determine if an operational boundary discovered in flow chart 300 fully defines the operating region of the electronic device and is not part of an interior fault region within the operating region.

In step 410, the present embodiment returns to the beginning point, as defined in step 330. From the beginning point, the present embodiment searches points along the first direction for test results until reaching an operational limit point. Points within the operational limit lie within a region predefined by a user to protect the tested electronic device from damage. The present embodiment does not test the points between the beginning point and the operational limit. Instead, the present embodiment examines test results for those points between the beginning point and the operational limit. If any of those points have not been tested, then there are no test results for that point.

For example, looking at the plot diagram 200 of Figure 2, the beginning point has coordinates (1.95, 3.80). Continuing in the same direction as predefined in flow chart 300, adjacently coupled points are examined for test results in a first direction until reaching the operational limit. For example, in Figure 3, the direction of examination would be along the y-axis (the second parameter) in an increasing manner.

Continuing with step 410, the present embodiment sets the last point as a last failure point or operational point found in a first direction moving from the beginning point to the operational limit. Points with no test results have no bearing on the outcome of step 410.

In condition step 420, the present embodiment determines if the last point was an operational point. If the last point is not an operational point, then the plurality of boundary points is not part of an interior fault region. As such, the operational boundary defines the operational range of the electrical device and the process illustrated in flow chart 400 ends.

On the other hand, if the last point was an operational point, then the present embodiment proceeds to step 430. In this case, the process outlined in flow chart 400 has determined that the plurality of boundary points lies within an interior fault region. As such, the present embodiment sets the last point as the start point in step 430 and begins the process in flow chart 300 again. Specifically, from step 430, the present embodiment proceeds to "B," which leads back to step 310 in flow chart 300.

In this manner, by recursively applying the steps in the processes outlined in flow charts 300 and 400, a plurality of boundary points that define an operating region are discovered, and tested to determine if they define an interior fault region. This process is repeated, and may move back and forth between flow charts 300 and 400 repeatedly, until the plurality of boundary points are found not to be part of an interior fault region, and fully define the operating region of a tested electronic device.

While the methods of embodiments illustrated in flow charts 300 and 400 show specific sequences and quantity of steps, the present invention is suitable to alternative embodiments. For example, not all the steps provided for in the method are required for the present invention. Furthermore, additional steps can be added to the steps presented in the present embodiment. Likewise, the sequences of steps can be modified depending upon the application.

A method and apparatus for discovering an operational boundary and an operational range of an electrical device, is thus described. While the present invention has been described in particular embodiments, it should be appreciated that the present invention should not be construed as limited by such embodiments, but rather construed according to the below claims.

While the invention has been illustrated and described by means of specific embodiments, it is to be understood that numerous changes and modifications may be made therein without departing from the

spirit and scope of the invention as defined in the appended claims and equivalents thereof.